Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **APR 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **High-average Power Broadband 18-beam Klystron Circuit and Collector Designs**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,Vacuum Electronics Branch (Code 6840,4555 Overlook Avenue SW,Washington,DC,20375**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002087. Proceedings of the 2008 IEEE International Vacuum Electronic Conference (9th) (IVEC 2008) Held in Monterey, CA on April 22-24, 2008. U.S. Government or Federal Rights License

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**2**	

20.3: High-average Power Broadband 18-beam Klystron Circuit and Collector Designs

Khanh T. Nguyen* [1], *Edward L. Wright* [1], *Dean E. Pershing* [1], *John Petillo* [2], *David K. Abe, and Baruch Levush

Vacuum Electronics Branch (Code 6840)
Naval Research Laboratory
Washington, DC 20375
(knguyen@estd.nrl.navy.mil / 202-767-3897)

Abstract: *The circuit and collector designs for a high-average power S-band multiple-beam klystron are presented. The klystron will be powered by the recently completed 41.6 A, 42 kV, 18-beam electron gun. A compact circuit yielding 680-kW peak power and 13% 1-dB bandwidth has been designed. Design of a high-average power compatible collector for the klystron is also presented. Key issues such as collector power loading and particle reflections due to time-dependent virtual cathode formation set up by the spent (bunched) beam in the collector are addressed.*

Keywords: Multiple beam; S-band; electron gun; Klystron; collector; MBK.

Introduction

Fundamental-mode multiple-beam klystrons (MBK) offer the potential for high-power broadband amplification at low beam voltage in a compact circuit. This is the impetus for our MBK research and development effort. Our first MBK [1] was powered by a 45 kV, 32 A, eight-beam, electron gun [2], and the objective was to demonstrate beam generation and transport with and without RF. This narrow-band (~2%) 600-kW tube was successfully tested at the Naval Research Laboratory (NRL) [3]. Recently, a second MBK [4] also driven by the eight-beam gun was tested at NRL [5]. The technical objective of this MBK was to test our multi-gap MBK circuit design methodology to extend bandwidth while maintaining peak power output. Initial test results show 600-kW peak RF output power and a 3-dB bandwidth ~ 6 %, and the MBK is also stable against spurious oscillations [5].

The MBK design described in this paper is built on the knowledge and experience gained from previous eight-beam MBKs. However, this third MBK will be powered by the recently developed eighteen beam electron gun. This high-repetition rate (mod-anode pulsed) gun will provide a peak beam current of 41.6 A at the nominal operating voltage of 42 kV [6]. The higher beam current available from this gun permits an extension of the power-bandwidth product.

Circuit Design

The circuit design was performed using the particle-in-cell code MAGIC-3D [7]. Beam parameters from our 18-beam gun design are employed in the design simulations. The circuit is comprised of seven cavities in a total length of ~23 cm. All two-gap cavities operate in the π-mode with the same gap-to-gap coupling approach as used in our previous broadband 8-beam design [4].

The filter-loaded two-gap output cavity permits broadband and efficient RF power coupling from the bunched electron beam. In addition, the interaction impedance across the band can be tailored to compensate for any frequency-dependence of the beam gain current. This flexibility was used to produce the MBK frequency response shown in Figure 1

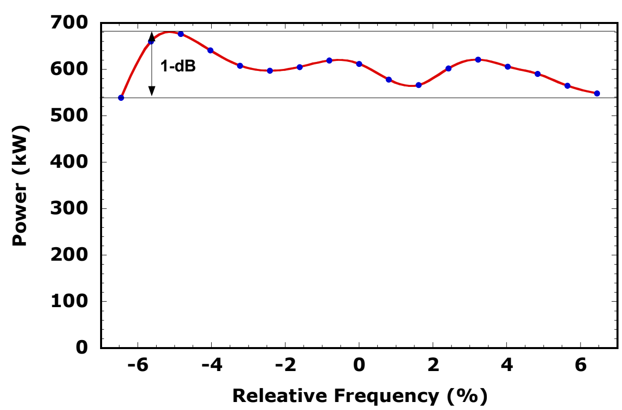

Figure 1: Frequency response of the circuit at 250-W of input power

Collector Design

The high-average power compatible collector design was performed using the 3-D gun and collector code

[1]Beam-Wave Research, Inc., Bethesda, MD 20814
[2]SAIC, Billerica, MA 01821

MICHELLE [8] and the magnet code MAXWELL-3D [9]. The magnetic field profile from the magnet design was imported into MICHELLE from MAXWELL-3D. The collector shape and magnetic field profile were designed in tandem to properly spread out the beamlets to ensure that the collector power loading is within the limit of current cooling technology. Shown in Figure 2 is the power deposition on the collector surface for the full-energy beam. The discrete nature of beamlet power deposition on the collector can be clearly seen. At the desired operating duty cycle, the maximum power loading is approximately 250 W/cm^2, well within available cooling limit.

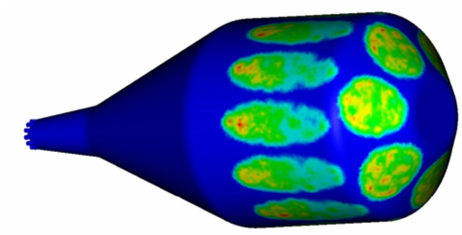

Figure 2: Power loading on 18-beam collector surface at full beam energy of 42 kV.

In the spent-beam case, the beam phase-space information was imported into MICHELLE from MAGIC-3D. Of particular import here is the optimization of the collector geometry near the entrance to minimize low-energy electron reflections caused by the virtual cathode (formed by collective space-charge depression). For this high-perveance fundamental-mode MBK collector design, particular attention was paid not only on the energy spectrum of the spent beam but also on the time-dependent nature of the bunched beam upon entering the collector. Figure 3 illustrates the current shape of a single bunch of the spent-beam, which shows the peak RF current can be a factor of six times higher than the average beam current.

This time-dependent behavior, if not properly taken into account, can lead to substantial and unexpected particle reflections, since the depth of the depression is function of the peak RF beam current. The time-dependent solver in MICHELLE was employed to model and confirm this scenario. Based on the MICHELLE model, we have incorporated into the collector design a feature to eliminate particle reflections due to virtual cathode formation. This feature will be presented and discussed.

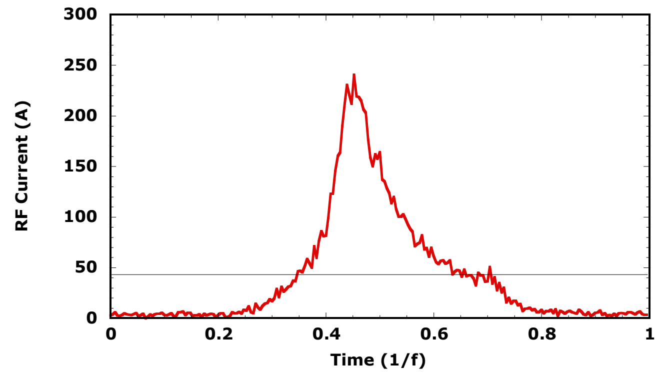

Figure 3: Beam RF current profile in a single period of the spent beam near saturation (average beam current of 41.6 A is also shown).

Acknowledgement

This work was supported by the Office of Naval Research and the US Army SMDC.

References

[1] K.T. Nguyen, et al, "*Electron gun design for fundamental-mode S-band multiple-beam amplifiers*," IEEE Trans. Plasma Sci., vol. 32, pp. 1212-1222, June 2004.

[2] K.T. Nguyen, et al., "*High-power Four-cavity S-band multiple-beam klystron design*," IEEE Trans. Plasma Science, vol. 33, pp. 1119-1135, April 2005.

[3] D.K Abe, et al., "*Demonstration of an S-Band, 600-kW fundamental-mode multiple-beam klystron*," IEEE. Electron Dev. Lett., vol. 26, pp. 590-592, Aug. 2005.

[4] K.T. Nguyen, D.E. Pershing, D. K. Abe, and B. Levush, "*Bandwidth Extension of an S-band Fundamental-Mode Eight-Beam Klystron*", IEEE Trans. on Plasma Science, vol. 34, p.576, June 2006.

[5] D.K Abe, et al., "*Experimental Demonstration of MBK2, an Eight-Beam, Five-Cavity Multiple-Beam Klystron*," IVEC 2008 (Monterey, CA).

[6] K.T. Nguyen, D.E. Pershing, D.K. Abe, G. Miram, and B. Levush, "*Eighteen-beam gun design for high power, high repetition rate, broadband multiple-beam klystrons*," IEEE Trans. Plasma Science, vol. 33, pp. 685-695, April 2005.

[7] Goplen, B., et al., *MAGIC User's Manual*, Mission Research Corp., Newington, VA, vol. MRC/WDC-R-380 (Oct. 1996).

[8] J. Petillo, et al, "*Recent Developments to the MICHELLE 2-D/3-D Electron Gun and Collector Modeling Code*," IEEE Trans. on Electron Devices **52**, May 2005.

[9] Ansoft Corporation, Pittsburgh, PA.